Life Cycle Management (Section Editor: Gerald Rebitzer)

Life Cycle Tools within Ford of Europe's Product Sustainability Index

Case Study Ford S-MAX & Ford Galaxy

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Abstract

Goal, Scope and Background. Sustainability is a well recognised goal which is difficult to manage due to its complexity. As part of a series of sustainability management tools, a Product Sustainability Index (PSI) is translating the sustainability aspects to the organization of vehicle product development of Ford of Europe, thus allocating ownership and responsibility to that function. PSI is limiting the scope to those key environmental, social and economic characteristics of passenger vehicles that are controllable by the product development organisation.

Materials and Methods. The PSI considers environmental, economic and social aspects based on externally reviewed life cycle environmental and cost aspects (Life Cycle Assessment, Cost of ownership / Life Cycle Costing), externally certified aspects (allergy-tested interior) and related aspects as sustainable materials, safety, mobility capability and noise. After the kick-off of their product development in 2002, the new Ford S-MAX and Ford Galaxy are serving as a pilot for this tool. These products are launched in Europe in 2006. The tracking of PSI performance has been done by engineers of the Vehicle Integration department within the product development organization. The method has been translated in an easy spreadsheet tool. Engineers have been trained within one hour trainings. The application of PSI by vehicle integration followed the principle to reduce the need for any incremental time or additional data to a minimum. PSI is adopted to the existing decision-making process. End of 2005, an internal expert conducted a Life Cycle Assessment and Life Cycle Costing (LCC) study for verification purposes using commercial software. This study and the PSI have been scrutinized by an external review panel according to ISO 14040 and, by taking into consideration the on-going SETAC, work in the field of LCC.

Results. The results of the Life Cycle based indicators of PSI as calculated by non-experts are fully in line with those of the more detailed expert study. The difference is below 2%. The new Ford Galaxy and Ford S-MAX shows significantly improved performance regarding the life cycle air quality, use of sustainable materials, restricted substances and safety compared to the previous model Galaxy. The affordability (Life Cycle Cost of Ownership) has also been improved when looking at the same engine types. Looking at gasoline versus diesel options, the detailed study shows under what conditions the diesel options are environmentally preferable and less costly (mileage, fuel prices, etc.).

Discussion. The robustness of results has been verified in various ways. Based also on Sensitivity and Monte-Carlo Analysis, case study-specific requirements have been deduced defining criteria for a significant environmental improvement between the various vehicles. Only if the differences of LCIA results between two vehicles are larger than a certain threshold are the above-mentioned results robust.

Conclusions. In general terms, an approach has been implemented and externally reviewed that allows non-experts to manage key environmental, social and economic aspects in the product development, also on a vehicle level. This allows mainstream functions to take ownership of sustainability and assigns accountability to those who can really decide on changes affecting the sustainability performance. In the case of Ford S-MAX and Galaxy, indicators from all three dimensions of sustainability (environment, social and economic) have been improved compared to the old Ford Galaxy.

Recommendations and Perspectives. Based on this positive experience, it is recommended to make, in large or multinational organizations, the core business functions directly responsible and accountable for managing their own part of environmental, social and economic aspects of sustainability. Staff functions should be limited to starting the process with methodological and training support and making sure that the contributions of the different main functions fit together.

Keywords: Automotive studies; design for environment; life cycle assessment (LCA); life cycle costing (LCC); product design; sustainability; sustainable development; vehicles

Introduction

The Brundtland Commission defined sustainable development as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. The concept is explicitly, and simulateously, attempting to improve environmental, social and economic aspects. Ford of Europe's Product Sustainability Index (PSI) is one step, and one option, to implement the vision "to provide the world with mobility by making it sustainable" [2]. The concept behind this Product Sustainability Index (PSI) is to define those key and controllable, but limited, product attributes that define the sustainability of a vehicle – from a product development perspective. As it also covers non-environmental aspects, it has to go beyond the concept of ISO TR 14062, that is guiding the integration of environmental aspects in product development [3]. Other social, environmental and economic perspectives

are captured by other Ford Sustainability Indices, focussing on different aspects (e.g. related to quality, labor, etc.). The main idea is that the meaning of sustainability is individually translated for each of the main functions of the organisation (besides Product Development in particular Manufacturing, Human Resources and External Affairs). By doing so, the understanding, ownership and responsibility can be best allocated in complex organisations. The article is not looking at social life cycle approaches [4–6], or checklist and guidelines approaches [7], as being subject for other corporate funtions or industries.

The focus of this article is the question of how to disseminate the use of life cycle based tools – as PSI – in a way that non-experts can directly apply life cycle tools in managing their business while ensuring a minimum of resources for calculation and a maximum of accuracy.

Process	Lead Responsibility
PSI Methodology	CC / Product Planning
Data input	Individual Data owner
PSI Calculation	Vehicle Integration (VI)
PSI Target Setting, Reporting, Compliance	CPE / Project Manag'nt / Vehicle Integration
Integration / Awareness / Training	PD Factory
External Communication	Purchasing
Cross Carline Co-ordination	Product Planning
Governance	FoE Operating Committee

Fig. 1: Roles & Responsibilities within the PSI process of implementation and integration within product development (PD) (CPE = Chief Programme Engineer, CC = Corporate Citizenship department)

1 Method and Implementation of Ford of Europe's PSI

There is not yet an agreed upon international standard for measuring the product sustainability. However, the PSI indicators to be presented herein are partially based on the ISO 14040 (Life Cycle Assessment) standard and the current work of SETAC Europe on Life Cycle Costing [8]. These aspects are in the focus of this paper while the selection of PSI indicators and the methodology of non-life cycle indicators have been discussed in a previous paper [9]. Specifically, PSI incorporates eight indicators reflecting environmental (Life Cycle Global Warming Potential, Life Cycle Air Quality Potential, Sustainable Materials, Restricted Substances, Drive-by-Exterior-Noise), societal (Mobility Capability, Safety) and economic (Life Cycle Cost of Ownership) vehicle attributes. The nomenclature 'Product Sustainability Index' has been selected for internal reasons when the development work started 4 years ago. Contrary to what the word 'index' seems to suggest, the PSI is not reduced to a single final score – sustainability is by definition not a one-dimensional issue. It is always measured by various sets of indicators. There is no reasonable way to combine aspects as diverse as safety, use of materials, and costs into one number. This would require, for example, a socially acceptable weighting of their relative importance. Global companies with global markets face the challenge of being confronted by differing values in their various markets and production locations. Further reasons have been shared in a previous paper [10].

PSI was implemented from the top down, with a process-driven approach. Process-driven means that PSI has been linked in the conventional Ford product development process from the very beginning. For example, PSI is included in particular in the so-called 'multi panel chart' where all vehicle attributes (craftsmanship, safety, environment, costs, etc.) serve as a kind of Multi-Criteria Requirement Matrix where the status is tracked towards the targets given from the beginning through all development milestones.See also advanced approaches for Multi-Criteria Decision Analysis (MCDA) as recently applied to LCA [11]. It was a top-down approach, in that it was called for and authorized by senior management. The roles and responsibilities involved, with the exception of the development of initial methodologies, were taken on by Product Development itself, without relying on a specialist group internal or external to Product Development. This ensures that PSI is optimally integrated into Product Developmention, since it is executed by the same people also running other aspects of product development (**Fig. 1**).

Ford's LCA specialist has developed a comprehensive, though very simple spreadsheet file to enable non-specialists to track PSI progress. With the central input of the few data, the PSI – including the simplified Life Cycle Studies – are tracked from beginning to end. The majority of the data needed is readily available in the above-mentioned 'multi panel chart'. The very few factors required above and beyond those include main weight actions such as material changes to the predecessor and certain data about the air-conditioning systems. The engineers responsible for the simplified PSI tracking were given one hour training sessions that allowed them to understand the fundamental concepts, use the analysis spreadsheets and conduct simplified Life Cycle Studies (regarding environmental and cost aspects), and track the other PSI indicators. The aim of this very lean management of sustainability within Product Development is to avoid unnecessary administrative burdens and the need for additional resources, while still ensuring that sustainability is an integral part of the complex product development process.

The product development, decision-making process is supported by PSI in various ways. For example, PSI mirrors the consequences of design decisions driven by other vehicle attributes (e.g. performance, quality, craftsmanship) for eight indicators of sustainability. In addition, PSI provides the necessary information for some trade-off decisions: a more holistic assessment of weight reduction measures is viable by PSI as showing the:

- Environmental bottom-line impact balancing differences in the material production versus the improved use phase.
- Economic consequences balancing the potential on-costs against reduced fuel costs and changed maintenance or insurance costs.
- Non-Life Cycle related information including also potential material impacts, for example to safety.

This also allows for efficiency approaches in decision-making (for example environmental business cases [12]; eco-efficiency [13]). Additional decision support aspects of PSI (in particular related to benchmarking) will be the subject of further publications. Further, the concept of PSI is extracting selected main results of life cycle tools and is completing these by other, non-life cycle aspects. By doing so, different aspects – that cannot all be appropriately covered by current Life Cycle tools – are integrated in the decision-making process. PSI is adopted to the general decision-making process of product development (in particular the senior management milestone reviews based on multi-panel charts), but it is broadening the information basis and adding the perspective of sustainability.

Each manufacturer has its own, company-specific, automotive product development process. The PSI approach described fits only to the Ford design processes and culture. It is not suggested that this approach will also suit other company cultures or markets since the methodologies and approaches cannot be generalized [3]. External regulatory bodies applying mandatory approaches would be counterproductive, also since a one-size-fits-all approach does not work here – since sustainable practices can only work based on a solid internal basis of understanding, drivers, motivations and commitments – not based on rules and regulations. The PSI is a voluntary approach that aims to integrate environmental, social and economic aspects into product development as part of Ford's commitment to sustainability.

2 Life Cycle Aspects

The environmental aspects are tracked following the ISO 14040 for Life Cycle Assessment (LCA). For the economic aspects, two conventional Life Cycle Costing (LCC) studies have been performed in line with the findings of the most recent scientific European working group in this field [8]. During product development, simplified LCA and LCC are carried out by non-specialists. Before vehicle launch, a Ford LCA and LCC specialist verifies the initial results, doing a more detailed LCA based on specialized software and using an extended database [14]. The basic method of this LCA is the same as that used in another automotive study that was independently reviewed according to ISO 14040 [15]. However, additions have been made to include modern vehicle technologies (electronics, air-conditioning, emission control) not considered previously as well as data specific to the current project.

2.1 Goal and scope definition

The main goal of the Life Cycle Studies is to support the internal Product Development by tracking the environmental life cycle impact of the planned and taken engineering actions – as part of PSI throughout the product development process for key environmental (global warming potential and air quality potential) and economic aspects (LCC), and finally verify the PSI results involving also other agreed upon environmental impacts.

The functional unit is defined as follows: a European, premium, mid-class, van-sized, five-door vehicle for a minimum of 5 passengers, including a luggage compartment with a minimum volume of 900 l, climate-controlled interior, modern entertainment and safety standards with an average mileage of 150,000 km over 12 years. An additional LCC value is identified for the case of a resale after 3 years.

Five vehicles have been assessed:

- Previous Ford Galaxy 1.9 l TDI, manual 6 speed, economy,
- New Ford Galaxy 2.0 l TDCi with DPF trend edition,
- New Ford Galaxy 2.0 l, trend edition,
- New Ford S-MAX 2.0 l TDCi with DPF trend edition,
- New Ford S-MAX 2.0 l trend edition.

The base data for vehicle production is the material breakdown of the different vehicles. These are derived from:

- A complete teardown of the previous Ford Galaxy in the Ford dismantling center in Cologne.
- Weight assumptions based on the predecessor platform and planned weight actions (for the first life cycle study at the start of the vehicle development of the new Ford vehicle models – gateways Kick-off (KO) to Programme Approval (PA)).
- Weight engineering data of the new Ford vehicles models (for life cycle studies during product development – from gateways PA to Product Readiness (PR).
- IMDS data of the new Ford vehicles models [16] completed by engineering data – for gateway Change Cut-off (CC) and for verification life cycle study before launch.

It should be noted that, in order to avoid complicating this work beyond the point of practicability, the vehicle models chosen represent the normal weight-control models. Similarly, no additional supplier information has been requested to avoid further complication.

The principal system boundaries, data requirements and data used for the LCA study, as well as the considered elementary flows and impact assessment scope, are mainly identical those from a previous study [15] (based on recent CML approach [17] for LCIA [18]). Based on this, the LCC studies are approximating the production part via the price and are capturing the use phase as in the LCA study. The full LCC study covers the end-of-life phase analogous to the LCA study. The additional cost-of-ownership LCC study is covering only 3 years of use and ending the life cycle via the residual value (**Table 1**). The cost-of-ownership study is necessary to add the perspective of the direct customer in product development decisions. A monetarization of enviromental aspects is not done, as being not helpful to integrate this perspective, to avoid double counting (with aspects covered by LCA) and for fundamental issues linked to those methodologies as detailed in a previous paper [12]. From the authors' perspective, it is not reasonable to try to put a 'price on sustainability' [19], but rather to transparently present the different aspects of sustainability [5].

The LCA study is very similar to a previous, automotive LCA study [15] regarding modeling of production, use and

Table 1: Processes included in the system boundaries for all vehicles

	LCA	LCC	Cost-of-Ownership
Production phase			
Raw Material Extraction	Yes via generic LCI data [14,15] applied to vehicles' material breakdown	Vehicle Price	Vehicle Price
Material production & processing			
Energy process, waste management			
Paint & Assembly process	Yes, specific LCI data		
Use phase			
Fuel production and consumption, refilling of fluids	Yes (12 years, 150,000 km)	Yes (12 years, 150,000 km)	Yes (3 years, 37,500 km)
Other Maintenance processes	Not included [6]	Yes (scheduled maintenance)	Yes (scheduled maintenance)
Vehicle Taxation and Insurance	Not applicable	Yes	Yes
End of Life			
Pre-treatment, Shredding	Yes	Yes	Residual Value
Recovery / Recycling process	Yes (50% / 50%)	Yes (50% / 50%)	
Monitoring, overhead, etc.	Not applicable	Yes	

EOL, although it includes the following, thus making it more comprehensive:

- More components (in particular diesel particulate filter (DPF), catalytic converter, air-conditioning, electronics),
- Assembly and paint data specific for the Ford vehicles,
- Maintenance in use phase (refrigerant and oil refilling),
- Non-tailpipe emissions in use phase (refrigerant leakage),
- Additional fuel consumption for the use of air-conditioning,
- Disposal of glass and electronics, recycling of catalytic converter, DPF and R134a.

The preceeding list should not be viewed, per se, as a fixed list for all LCAs on vehicles, but rather as the most appropriate set based on the experience of the authors for the vehicles produced by Ford.

2.2 Critical review panel and limitations

The LCA verification study is targeted at both an internal and external audience and includes comparative assertions. Therefore, an independent, third party critical review according to ISO 14040 (7.3.3) was undertaken at the end of the project. This was to ensure that the study is conducted in accordance with the international ISO standard 14040 series and is in line with current best practices for the Life Cycle Costing element. The chairman of the small review panel, David Hunkeler, has had previous experience in both fields. He was involved in reviewing a similar LCA study [15] and held the chairmanship of an LCC scientific working group. He selected the second reviewer, Walter Klöpffer, who has not been involved in the above mentioned LCA study [15].

The limitations of the LCA study are similar to those previously mentioned [15]. It is, for example, not possible to compare the results of this complete vehicle study with results of other complete vehicle studies. Complete LCAs consider different system boundaries, vehicle features included and use phase assumptions – for example, this study also considers the additional fuel consumption of air-conditioning that is not covered by most published, complete vehicle LCAs. This study does not transfer, to impacts, data for which the quality is highly questionable, such as those related to toxicity and landscape. Despite the limitations of the study, the chosen model and assumptions allow meaningful conclusions to be drawn regarding the main issues outlined above for the following reasons.

- Central specifics of the considered vehicles are considered,
- The assumptions, system boundaries and data approaches for the considered vehicles are fully aligned,
- Data analysis shows how significant and robust potential differences are in the result.

In the Life Cycle Costing and Cost-of-Ownership section, all figures are based on the set of assumptions about future trends made for the study. They can be considered as broad indicators of tendencies only and are used solely for the purposes of a relative assessment between the vehicles. The figures are not exact and may change significantly in real market conditions. Neither the author nor Ford Motor Company makes any guarantee that the costs reflect market conditions.

3 Environmental Life Cycle Inventory (LCI) and Cost Data Inventory

For the inventory, only data sets have been used that meet the minimum requirements. Detailed references are provided in a previous paper [15]. The above-mentioned additional data are coming from [14] (electronics) or are coming from a Ford database (catalytic converter, R134a, DPF, assembly, paint, use phase data, LCC data). These data have been discussed with the external reviewers. For one data set (corderite), an approximation had been necessary that has been checked in a sensitivity analysis. During the product development, in particular the weight and use phase data have been based on changing sources depending on avail-

Table 2: Overview on changing weight and material information along the product development (example Diesel vehicles) in kg *(milestones Kick-off (KO), Programme Approval (PA), Programme Readiness (PR) and Change Cut-off (CC))*

	New Ford Galaxy 2.0 l DW10 MMT6 cDPF Trend edition					New Ford S-MAX 2.0 l DW10 MMT6 cDPF Trend edition				
Milestone	**Ferrous [a]**	**Other metals**	**Glass & Ceramics**	**Plastics & Elastomers**	**Fluids& other**	**Ferrous [a]**	**Other metals**	**Glass & Ceramics**	**Plastics & Elastomers**	**Fluids& other**
KO	1,034	194	48	355	27	992	187	46	348	21
PA	1,068	199	49	366	28	1,023	192	48	358	22
PR	1,052	197	49	362	34	1,025	192	48	351	36
CC	>1,005	246	50	<355	37	>981	244	50	<329	27

[a] Note: at CC also more details regarding the kind of alloys have been available

ability during the product development (**Table 2**). For verification, the weight assumptions of the gateway <CC> have been used.

The studied vehicles have the following fuel consumption:

- Previous Ford Galaxy 1.9l TDI, 6.5 l diesel/100 km,
- New Ford Galaxy 2.0 l TDCi with DPF Trend edition, 6.5 l diesel/100 km,
- New Ford Galaxy 2.0 l, Trend edition 8.2 l gasoline/100 km,
- New Ford S-MAX 2.0 l TDCi with DPF Trend 6.4 l diesel/100 km,
- New Ford S-MAX 2.0 l Trend 8.1 l gasoline/100 km.

All new vehicles comply to the emission standard Euro 4 (for example, maximally 0.08 g NO_x/km for gasoline vehicles, or respectively 0.25 g NO_x/km for diesel vehicles), while the previous Ford Galaxy complies to Euro 3 (0.5 g NO_x/km). The SO_2 emissions are calculated based on an assumed fuel sulphur content of 50 ppm. Different to other complete vehicle life cycle assessment studies, also the fuel consumption due to the air-conditioning is assumed – increasing the above-mentioned values by up to 10%. Also the R134a leakage rate is considered (sensitivity analysis has been performed on available test data) to be affecting the global warming potential.

For the cost calculation, fuel prices are assumed to be at € 1,229 / litre premium gasoline, € 1,099 / litre diesel (variation in sensitivity analysis). Insurance costs are estimated based on a country specific set of premiums based on a standard set of individual insurance classes and is indicative only (ratings respective to engineering targets, a 55% deductible, insurance tariff 'R' of Ford insurance, without bonus). All use phase costs are discounted, assuming an interest rate of 8% and 2% inflation. This reflects private consumer interest rates and general European inflation numbers.

4 Life Cycle Impact Assessment and Theoretical Life Cycle Costing Result

The impact categories for climate change (indicator; Global Warming Potential, GWP) and Summer Smog (indicator: Photochemical Creation Potential, POCP) have been targeted and tracked as part of the product development process. Based on the changing weights, materials and fuel consumption, varying results have been reported at the different product development milestones (see Table 2). Vehicle Integration engineers carried out these calculations (non-LCA experts using the previously mentioned spreadsheet files). For verification purposes, a Ford LCA expert using LCA expert software has made calculations for the same vehicle based on the same data as available at the milestone CC (**Fig. 2**). The difference between the final results of both approaches is below 2%. In the verification of LCA more impact assessment categories are calculated based on the inventory results for the studied Ford Galaxy and S-MAX vehicles (**Fig. 3**). Based on the inventory of costs and the discounting rules a kind of cost impact assessment is done, i.e. what is the present value of the different costs along the life cycle (**Table 3**).

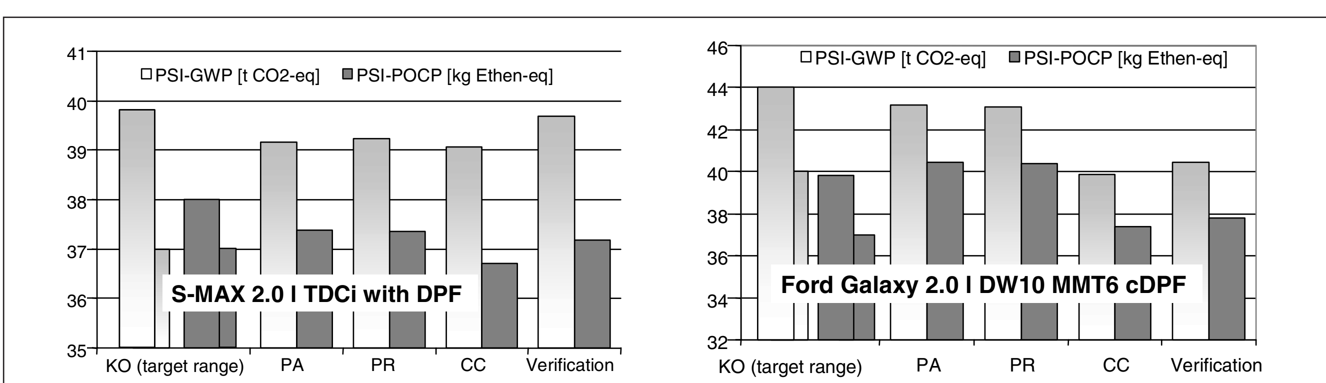

Fig 2: Global Warming Potential (GWP) and Photochemical Ozone Creation potential (POCP) of two Ford vehicles as calculated with a simple non-expert spreadsheet file at the gateways Kick-off (KO), Programme Approval (PA), Programme Readiness (PR) and Change Cut-off (CC) compared to verification by an LCA expert

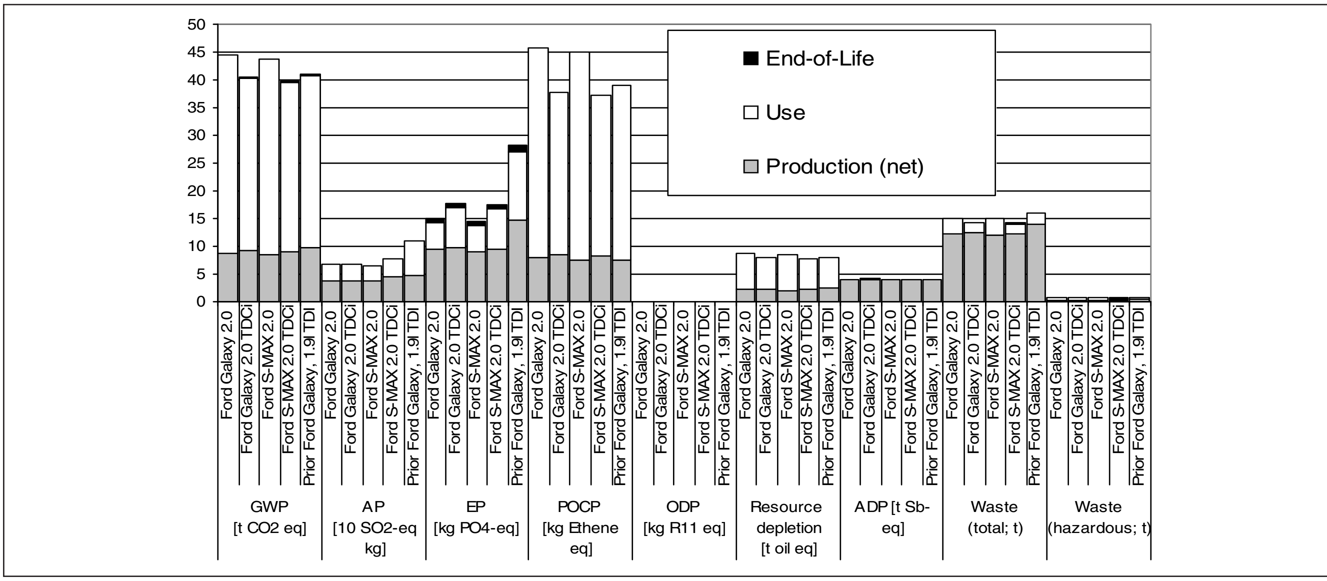

Fig. 3: Life Cycle Impact Assessment results for the studied Ford Galaxy vehicles

Table 3: Theoretical Life Cycle Costing and Cost-of-Ownership Results

Theoretical costs along the product life cycle	Ford Galaxy 2.0 l (gasoline)	Ford Galaxy 2.0 l TDCi with DPF	Previous Galaxy 1.9ITDI	Ford S-MAX 2.0 (gasoline)	S-MAX 2.0 l TDCi with DPF
Price € incl options	€ 27,475	€ 29,825	€ 29,700	€ 25,800	€ 28,150
Discounted use phase costs € [a] (3 years)	€ 8,938	€ 8,498	€ 8,707	€ 8,870	€ 8,389
Residual value after 3 years [a] (forecast)	60%	60%	56%	61%	61%
Discounted use phase costs € [a] (12 years)	€ 28,153	€ 26,767	€ 27,427	€ 26,424	€ 27,939
End-of-Life cost (consumer)	€ 0	€ 0	€ 0	€ 0	€ 0
Discounted Theoretical ELV profits (operators) [a]	min –€ 59	min –€ 67	min –€ 65	min –€ 60	min –€ 68
Theoretical Cost of Ownership [a] (3 years)	€ 22,525	€ 23,248	€ 24,396	€ 21,412	€ 22,073
Theoretical LCC [a] (12 years)	€ 55,569	€ 56,525	€ 57,062	€ 53,678	€ 54,505

[a] The authors and Ford Motor Company do not guarantee that the costs reflect the market conditions. Estimated value for one selected European market.

5 Interpretation

5.1 Data and dominance analysis

According to the review panel, the "quality of data and its transparency, as well as the extent of references seems appropriate for the study". Based on the share of the various life cycle phases (see Fig. 3), an identification of the environmentally dominating life cycle phases is possible. For the described vehicles, the use phase, including fuel production, accounts for most of the Life Cycle Global Warming Potential and Summer Smog Potential – this is mainly fuel economy driven. However, the sources of the emissions differ. While both sources of emissions are significant, the vehicle emissions dominate for GWP and, for POCP, the fuel production emissions dominate. This is also the reason for the use phase's large share of the overall total resource depletion, which includes crude oil that is between 70% for diesel and 75% for gasoline powered vehicles.

The production phase is the dominant life cycle phase for total waste with 81 to 88% – mainly due to metal mining waste. Heavier diesel vehicles come in at the upper end of this range. The production phase also accounts most for the abiotic resource depletion potential (ADP; 96 to 97%; mainly due to precious metals). For the acidification and eutrophication potentials there is a rough 60:40 split between production (higher; mainly due to metal mining and production including precious metals) and use phase. The one exemption is – due to the higher tailpipe emissions of the previous Galaxy. Here, the use phase has a share of 56% for the acidification potential. The relatively high material production impact is based on SO_2 emissions in the production of several metals (sulphur in ore) and the production of some plastics.

The share of the end-of-life phase is for all studied impact categories below 5%, but it has to be noted that the recycling of metals is reducing the environmental impacts of the production (see [15] for typical shares between total and net production. It is not the goal of this study to look at these aspects).

Looking at the economics (see Table 3), the vehicle price represents for all vehicles 54 to 57% of the overall life cycle costs (12 years). Looking at the use phase costs, the share of the fuel costs is, for these assumptions, below 50%.

5.2 Break-even, Monte-Carlo, sensitivity and scenario analysis

More informed decisions can be made based on LCAs if the uncertainties in the underlying LCA data is analysed and if the significance of identified differences in the resulting life cycle figures is determined [20,21]. Therefore, various Monte-Carlo analyses have been performed. One looked at the impact of changing the data by +/– 10% for fuel economy (due to uncertainties in actual air-conditioning consumption) and refrigerant leakage (new test procedures etc.) respectively by –10% to + 50% for the fuel price. The standard deviation looking across all vehicles, based on 1500 simulation runs is displayed in **Table 4**. Obviously, the impact of changes affecting the use phase is less important for EP, AP and total waste, while other indicators are more affected. The sensitivity of use phase assumptions is highest for the calculated costs as additional uncertainties are covered (alongside varying fuel economy and leakage rates that affect both LCA and LCC, fuel prices also play a role).

Another source of uncertain base data is the material composition of the vehicles (no final data available during the product development, late changes, etc.). Besides changing fuel economy data, this has been one of the reasons for the differences in the results from start (KO) to the end of the development process (CC) (see Fig. 2). The maximum difference resulting from these changes is up to 8% for GWP and POCP when considering also differences in the material production and painting/assembly data. This can be seen as a good surrogate for a significance criterion. That is, differences below 8% are not seen as significant for GWP and POCP – the same value as analysed for total waste, but care is necessary due to the above-mentioned data uncertainties based on dominance analysis. The respective values for AP, EP and resource depletion are up to 7%, while the differences for ADP and waste are much higher (ADP= 10–15%) due to the very specific linkages to the various types of materials. These thresholds will be used to analyse the significance of differences and the environmental break-even points. 'Significant break-even' refers to that mileage where one vehicle is significantly better than the other vehicle, i.e. in this case the environmental impact potentials are lower by at least 8% (GWP, POCP) or respectively 7% (AP, EP). Taking these required minimum thresholds, the following differences can be suggested to be significant taking into consideration a different sensitivity and scenario analysis:

Table 4: Standard deviations based on Monte-Carlo Analysis looking at changes in use phase assumptions

Impacted flow	Standard deviation
Use phase cost (€) [a]	12.20%
Abiotic Depletion (ADP)	3.02%
Resource depletion (EUROMAT)	3.82%
Acidification Potential (AP)	1.57%
Eutrophication Potential (EP)	0.97%
Global Warming Potential (GWP 100 years)	3.85%
Photochem. Ozone Creation Potential (POCP)	3.07%
Waste (total)	1.67%
Waste (hazardous, EWC)	3.17%
Primary Energy Demand	3.85%

[a] not discounted, use phase cost only; i.e. covering only 50% of the overall LCC. All LCIA and LCI standard deviations refer to the full life cycle.

- Galaxy 2.0l DW10 is environmentally superior to Galaxy 2.0l I4 in terms of GWP (break-even around 20,000 km mileage, but 'significant break-even' after 82,000 km), POCP ('significant break-even' after 37,000 km) as well as AP and EP ('significant break-even' already at 0 km),
- Galaxy 2.0l DW10 is environmentally superior to the previous Galaxy 1.9l TDI in terms of POCP (break-even 70,000 km; 'significant break-even' at around 450,000 km), AP and EP ('significant break-even' already at 0 km).
- S-MAX 2.0l DW10 is environmentally superior to S-MAX 2.0l I4 in terms of GWP (break-even around 20,000 km mileage but 'significant break-even' after 82,000 km), POCP ('significant break-even' after 37,000 km) as well as AP and EP (significant break-even already at 0 km),
- All new developed vehicles result in less total waste compared to previous Galaxy ('significant break-even' below 100,000 km).

Considering the economic aspects, there are large uncertainties for the end-of-life profits [12], but their overall impact is negligible (below 0.2%) of the total LCC. More significant is the uncertainty for the real insurance costs (highly dependent on personal contracts), the real maintenance costs (theoretical values are often worst case assumptions), fuel consumption and costs as well as the mileage (**Fig 4**). In the following, the economic break-even conditions can be deduced (a significance criteria has not been established – see also previous notes about the nature of these calculations and figures where no guarantee can be provided):

- Diesel versions might be economically preferable beyond 255,000 km over 12 years for the assumed yearly fuel, insurance and maintenance costs or around 200,000 km with costs at 50% of those assumed in the main scenario.
- The new diesel Galaxy version might be economically preferable beyond 250,000 km (S-MAX around 240,000 km) over 12 years for the assumed yearly fuel, insurance and maintenance costs but an interest rate of 4%.
- The new diesel versions might be economically preferable beyond 160,000 km over 12 years for the assumed yearly fuel, insurance and maintenance costs, but an interest rate of 4% and 50% higher fuel prices than in the main scenario.

The elasticity of results is larger for the LCC calculations than for the LCA calculations (compare [12]) as there is an

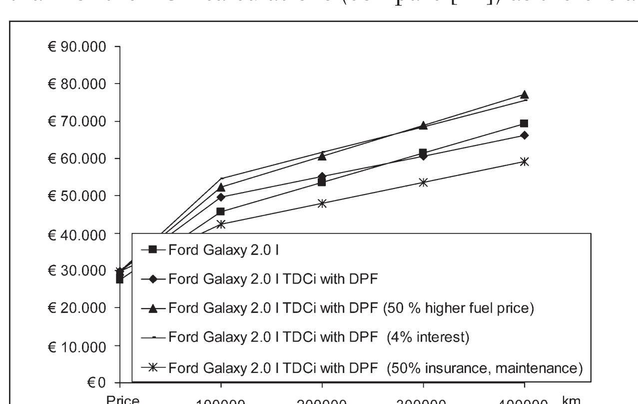

Fig 4: LCC for the studied new Ford Galaxy vehicles considering a mileage range, different fuel prices, interest rates as well as insurance and maintenance costs

additional set of assumptions for the LCC calculations – i.e. type of insurance costs, fuel prices and interest rates – that represent additional sources of uncertainty while these aspects have no impact on the LCA result.

6 Conclusions and Recommendations

Based on the Inventory, Impact Assessment and the sensitivity analysis, the following conclusions can be deduced:

– Environmental and economic break-even points could be identified for the new vehicles and for the different engine types as detailed in section 5.2.
– The calculations performed by non-LCA experts in Product Development (using the simplified spreadsheet tool) are in line with those calculated by the LCA expert (using an expert LCA tool). The differences, less than 2%, are insignificant (see Fig. 3), and the non-expert calculations can be used for PSI in parallel to the product development process.
– With PSI, Ford of Europe found a way to make life cycle tools applicable by non-experts with a minimum need for resources, without additional bureaucracy (voluntary approach integrated in anyway existing company-specific management tools of Product Development) but with high accuracy.

PSI is integrated in the existing Product Development and its decision-making process. As those being part of the decision-making process directly calculate PSI, the understanding of the outcome of life cycle tools is improved.

The example of Ford of Europe's PSI shows that the life cycle thinking is already fully integrated in industry. Of course further research and a continuous improvement in the tools and indicators might be necessary. But based on the experience of PSI, the authors strongly recommend leaving the decisions 'whether' and 'how' this is done only with the responsible functions within corporations. William McDonough's claim that regulation is (only) where design fails [19] means in return that where appropriate actions are already taken – like in this field – no regulation or policy making is necessary.

7 Critical Review Panel Report

The following is quoting the executive summary of the critical review report:

"Based on the documentation provided by Ford, as well as the general methodology employed and part of the data set from a previous study (LIRECAR) [15] for which the chairman of the present review panel was a member of the evaluation, the following statements have been formulated.

Ford has undertaken, within the specifications of ISO 14040, a cradle to grave LCA with an expert panel review a posteriori. The study has been appropriately defined, and reviewed, in accordance with ISO 14040 (ref paragraph 7.3.3). The sources and quality of the data, as well as its interpretation are of a very high level. The development of a reduced list of environmental indicators, as part of Ford's PSI, is valid and appropriate. The conclusions are supported by the data. The use of sensitivity, dominance and Monte Carlo analyses on key elements is well done. According to the reviewers' opinion, the LCA-part of the study is consistent with ISO 14040.

The two Life Cycle Costing (LCC) studies, which are part of Ford's evaluation, are not covered by ISO 14040ff. This work, for which an international standard is not yet available, can therefore be considered as an environmental life cycle costing, from the first user's perspective. This adds valuable information to the comparative assessment of the models investigated. The same is true for the societal aspects covered in this study which aim, within the limits of present-day methodology, to provide a full sustainability assessment."

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